Design and Fabrication of Nb_3Sn Cosθ Dipole Model at Fermilab

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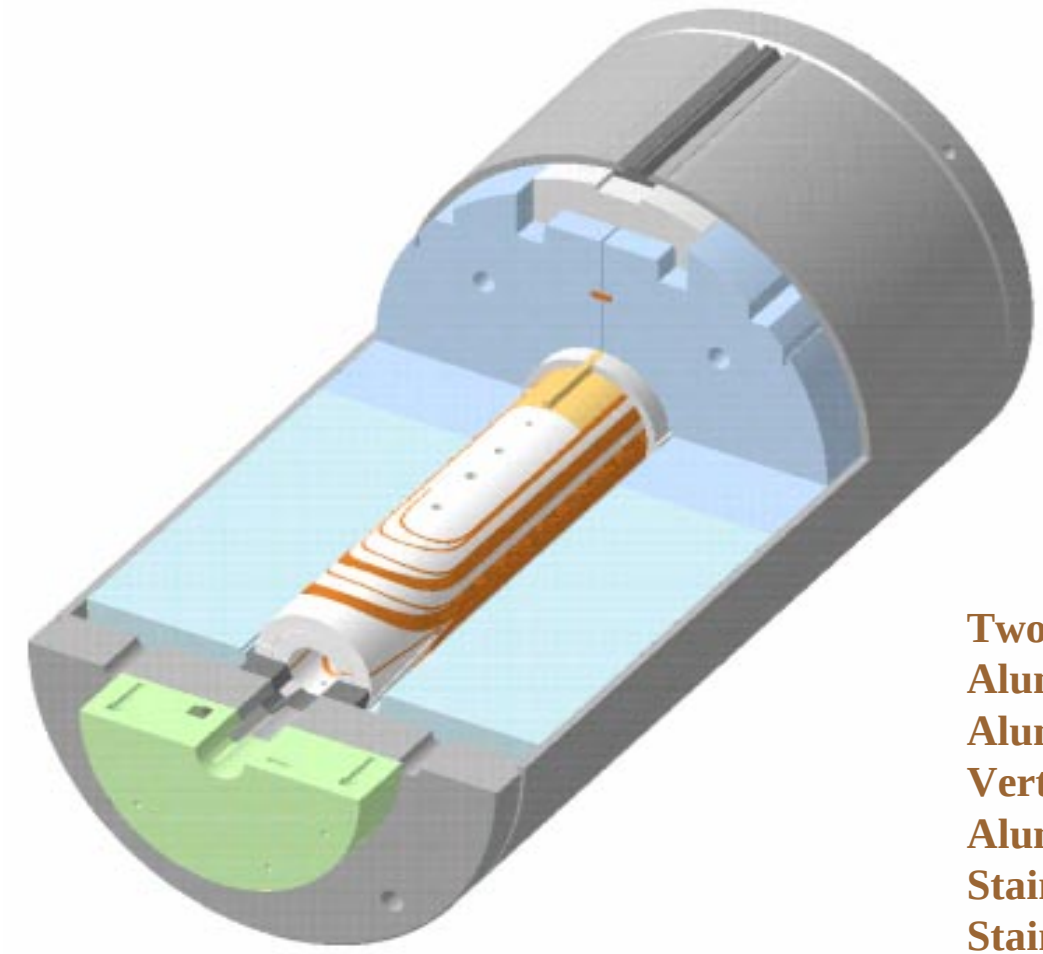
Outline

- Various Magnet Designs Investigated
- Dipole Model Fabrication
  - Cable Insulation and Wrapping
  - Coil Winding, Curing and Measuring
  - Coil Assembly and Reaction
  - Coil Impregnation
- Mechanical Analysis
  - Single Bore Design
  - 2-in-1 Designs
- Summary

Magnet Designs

(1) Single Bore Nb_3Sn Cosθ Dipole Magnet Design



Two Layer Coil Structure
Aluminum Bronze End Spacers and Poles
Aluminum Spacers
Vertically Split Iron Yokes
Aluminum Clamps
Stainless Steel Skins
Stainless Steel Skin Alignment Keys

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Magnet Designs: Single Bore Design

Design Features

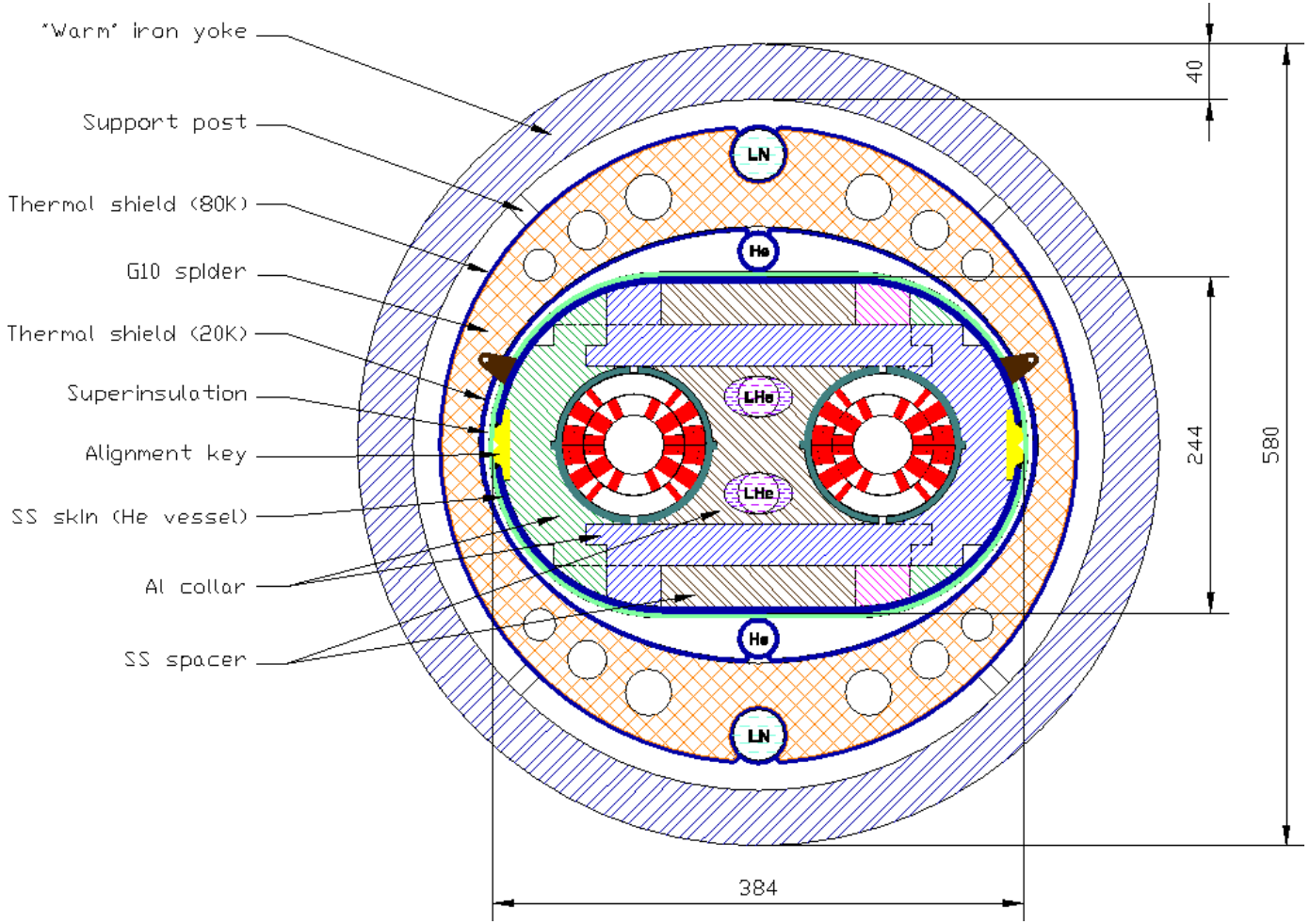
- Nb_3Sn Conductor Wind and React approach
- Ceramic Insulation with Ceramic Binder
- No interlayer Splice
- Simultaneous Reaction and Impregnation of two Half-Coils
- Spacers instead of Collars
- Vertical Gap between the two Iron Halves remains open
- Coil Prestress provided by aluminum clamps and Skin

Design Requirements

- Coil azimuthal prestress not to exceed 150 MPa
- Coil should remain under compression at all stages of the magnet
- Insulation capable of withstanding high reaction temperature

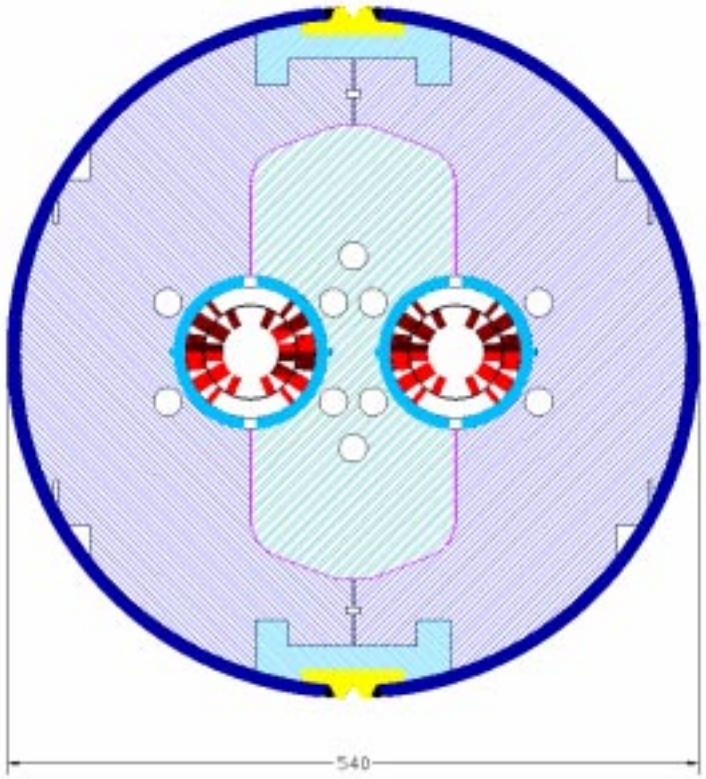
Magnet Designs cont...

(2) 2 - in -1 Nb_3Sn Cosθ Warm Iron Dipole Magnet Design



Magnet Designs cont...

(3) 2 - in -1 Nb_3Sn Cosθ Cold Iron Dipole Magnet Design



Same Coil Block Structure was used for all three different Designs

Before going on to the mechanical analysis it is important to understand the coil fabrication procedure.

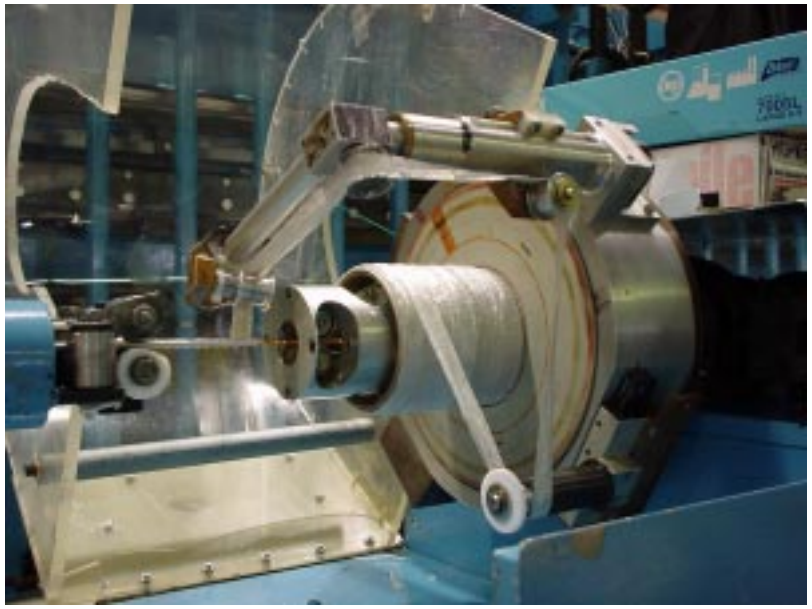
Coil Fabrication Procedure

Steps

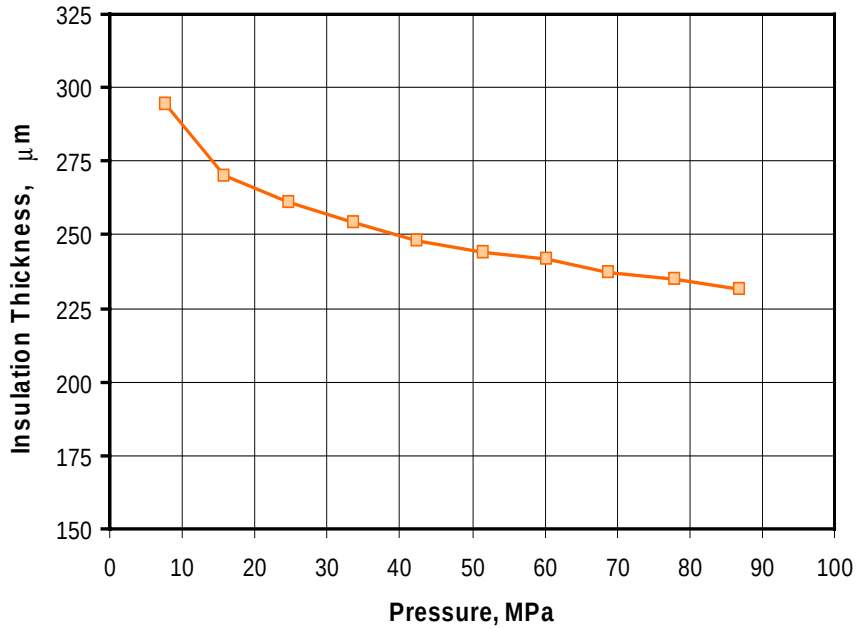
1. Cable Cleaning
2. Cable Insulation
3. Ceramic Binder Application and Curing
4. Inner Coil Winding
5. Application of binder to the Inner coil
6. Inner Coil Curing
7. Interlayer Insulation with Strip Heater
8. Outer Coil Winding on top of Inner coil
9. Application of binder to the Outer coil
10. Inner and Outer Coil Curing
11. Coil Assembly, Reaction and Impregnation

Insulation Wrapping and Binder Application

Insulation Wrapping Machine

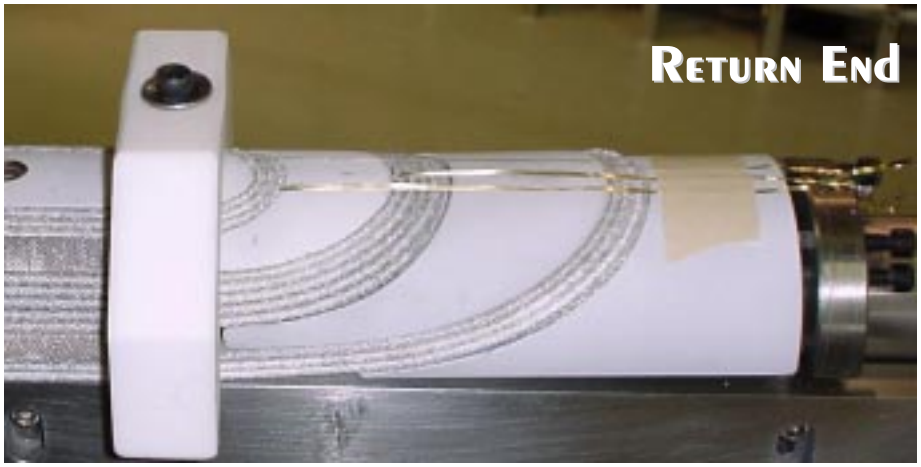


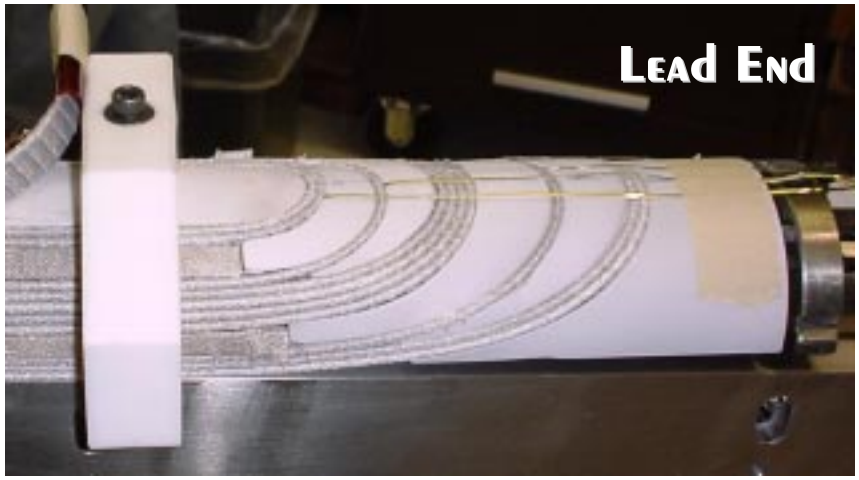
Mean Insulation Thickness for 50% Overlap after Binder application



Inner Coil Winding

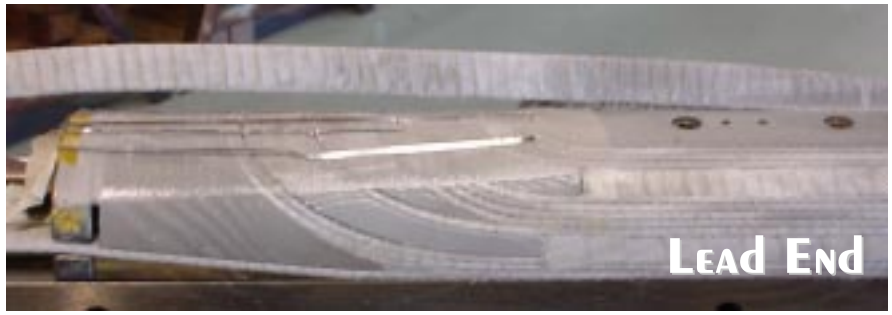
First Inner Coil before Curing





Inner Coil Curing

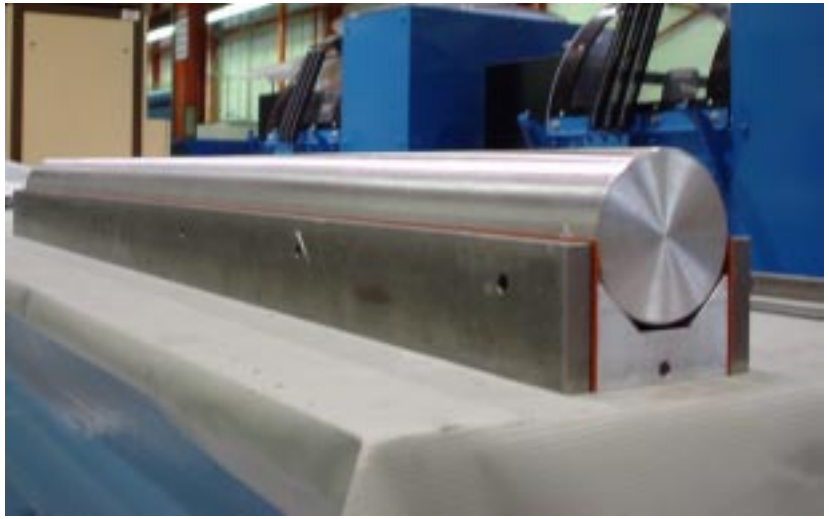
Cured Coil



Note: Coil was cured at 150 ºC for 30 min. The curing pressure was 40 MPa

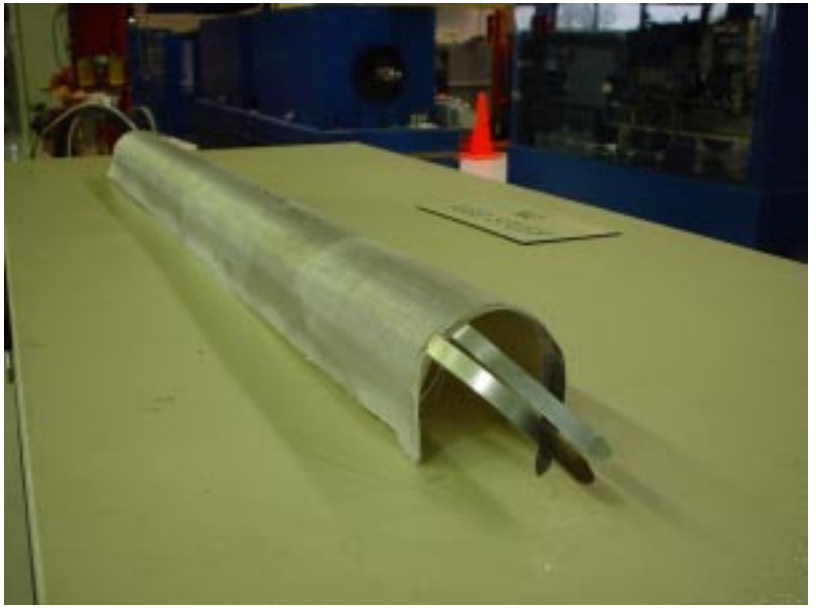
Interlayer Insulation with Strip Heaters

Tooling to make interlayer insulation



Middle layer of insulation with heater strips

Interlayer Insulation with Strip Heaters



Outer Coil Winding and Curing

After Curing

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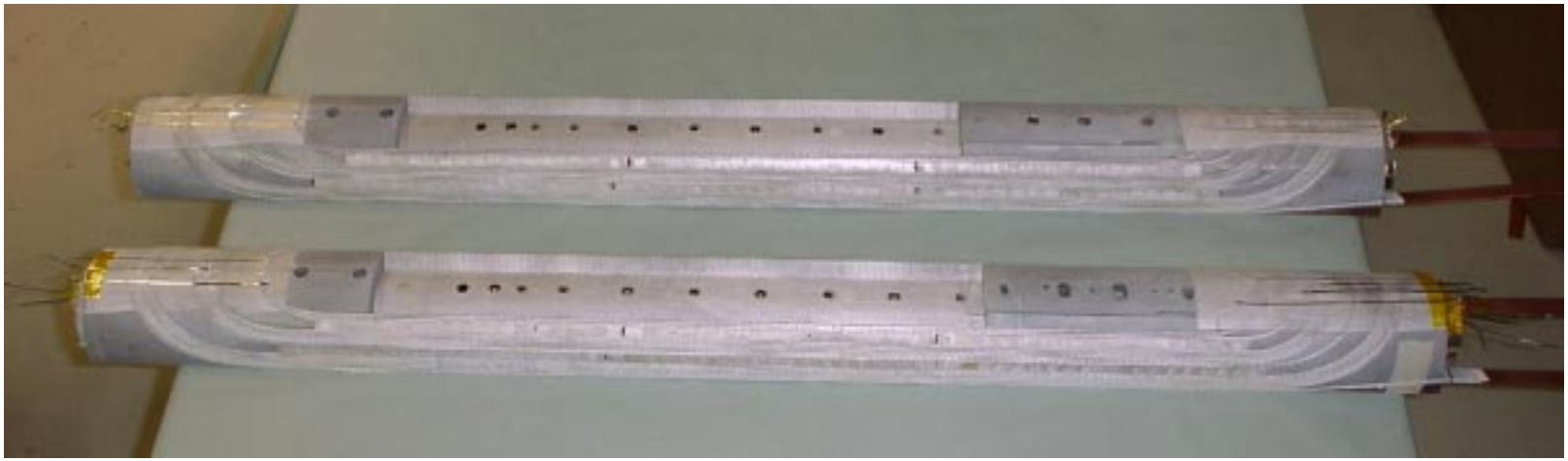
Dipole Model : Two Half Coils

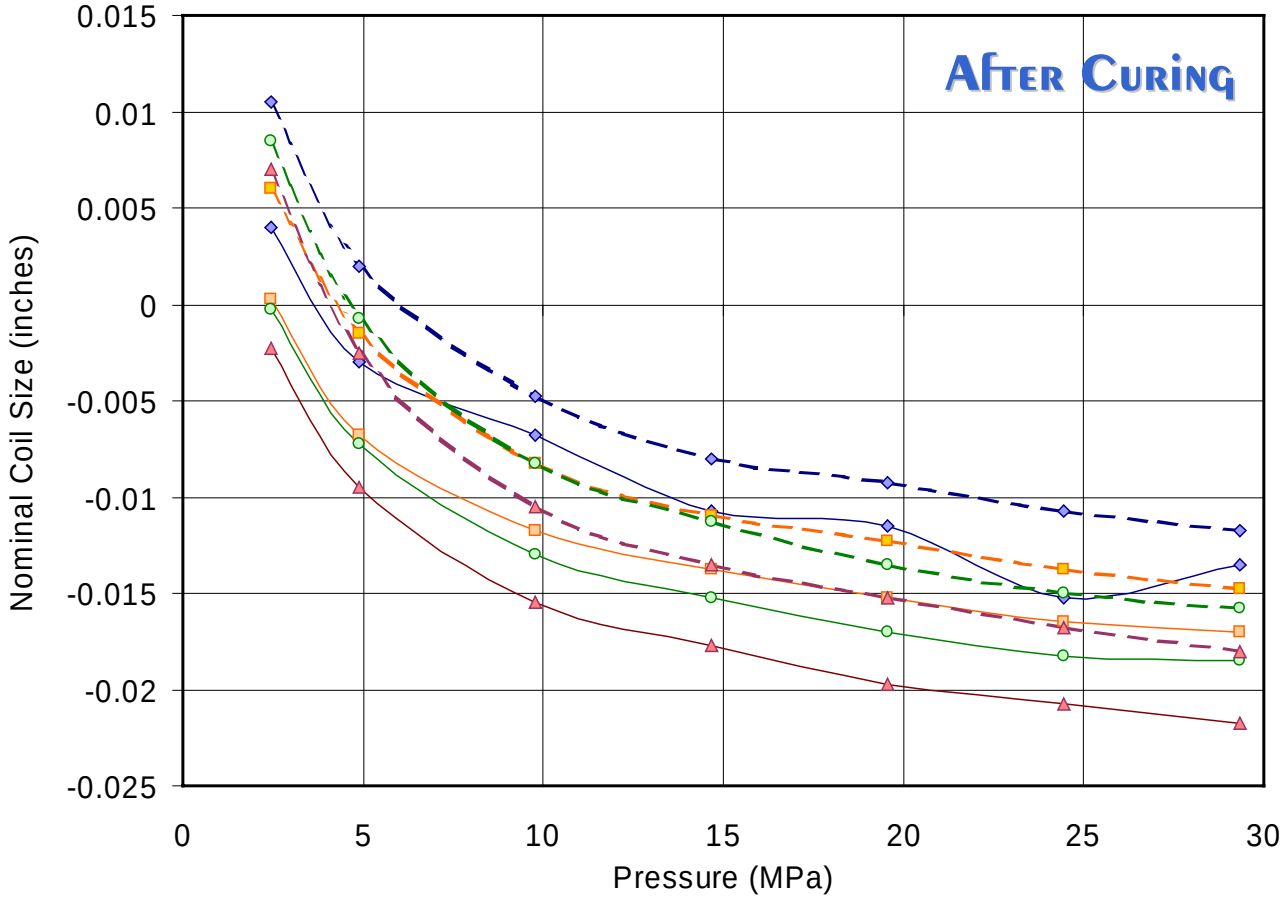


210.8 mm

445.4 mm

343.8 mm

Azimuthal Coil Size Measurements



Note: Measurements were taken at four different positions per half coil
Dashed Lines Represent First Half Coil
Solid Lines Represent Second Half Coil

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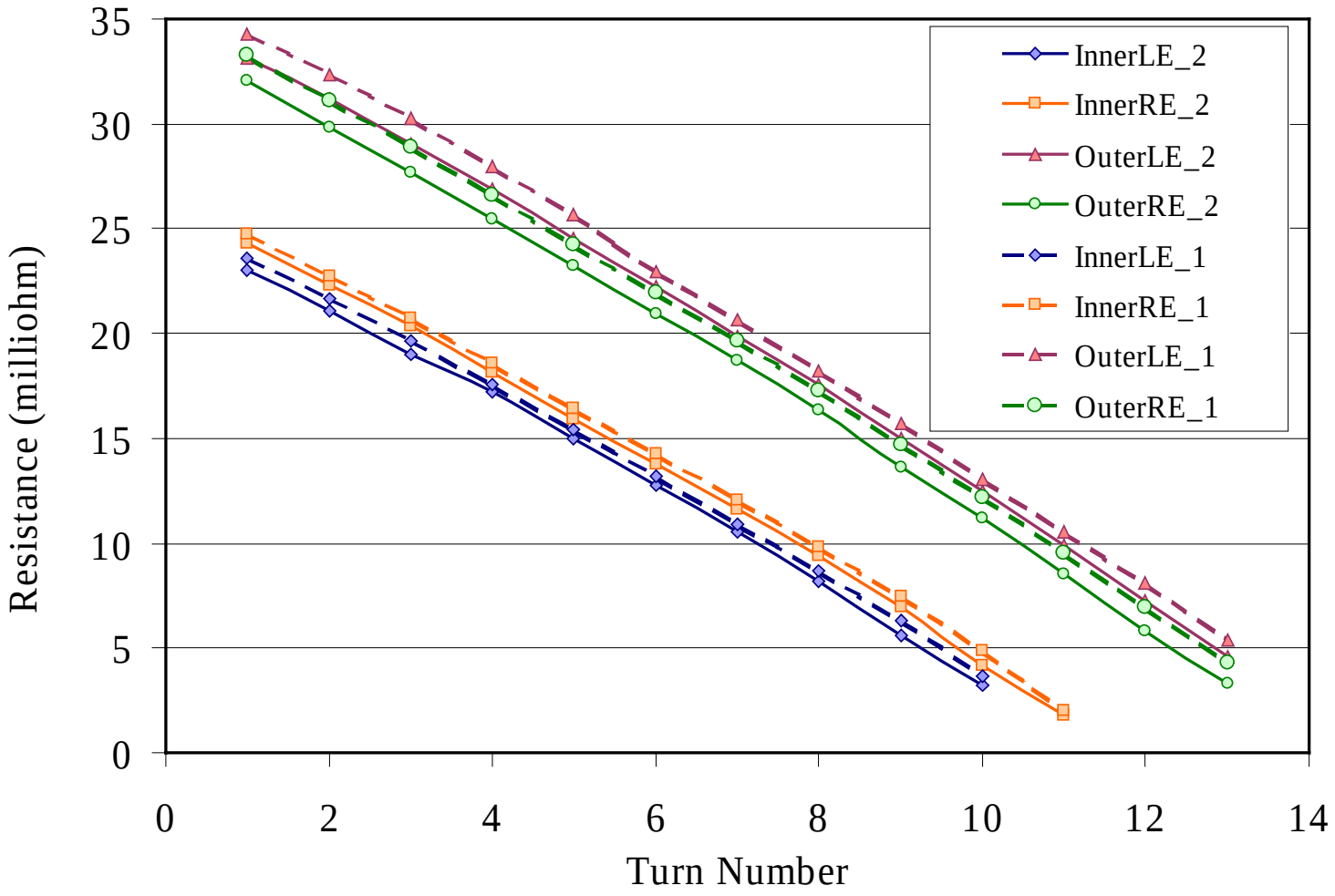
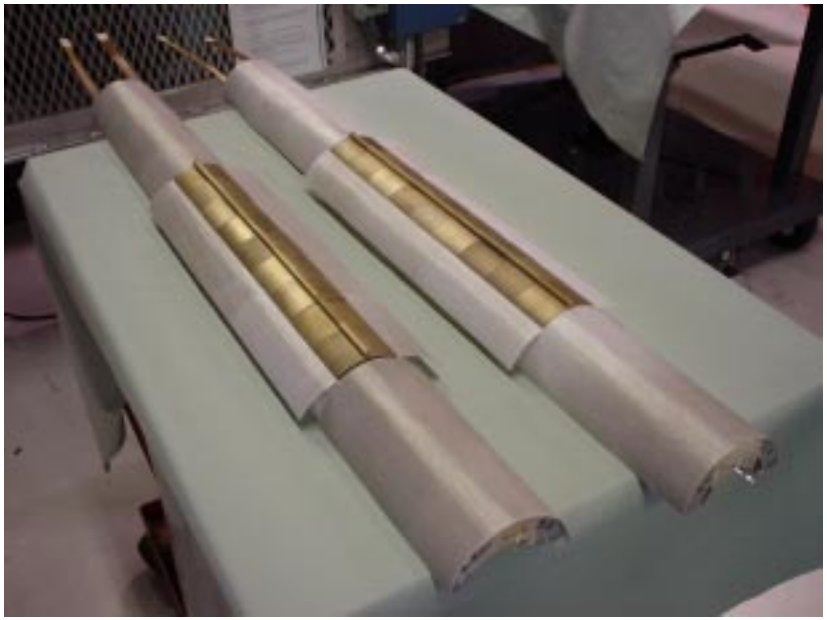
Turn - to - Turn Resistance Measurements



Note: Four Wire Measurement Technique with 0.1 mA current

Coil Assembly and Reaction

Coils with Ground Insulation and Outer Pole Pieces

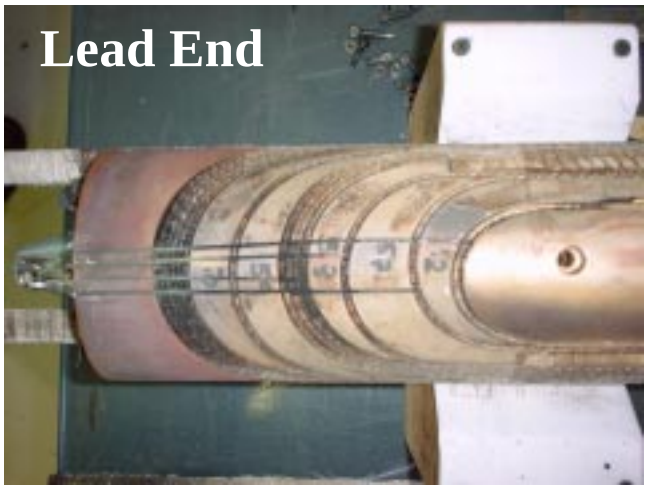


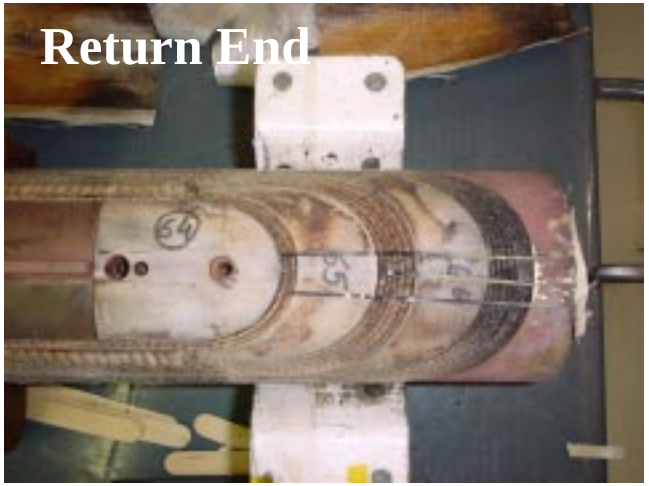
Coils Assembled in the Reaction Fixture

Current Status

- The reaction fixture has been assembled and placed in a Retort
- The retort is now being pumped for vacuum
- Coil Reaction is expected to start by the end of the week and last for 12 days. Note that the peak temperature is 700 C

Reacted Half Coil: Practice half Coil #2



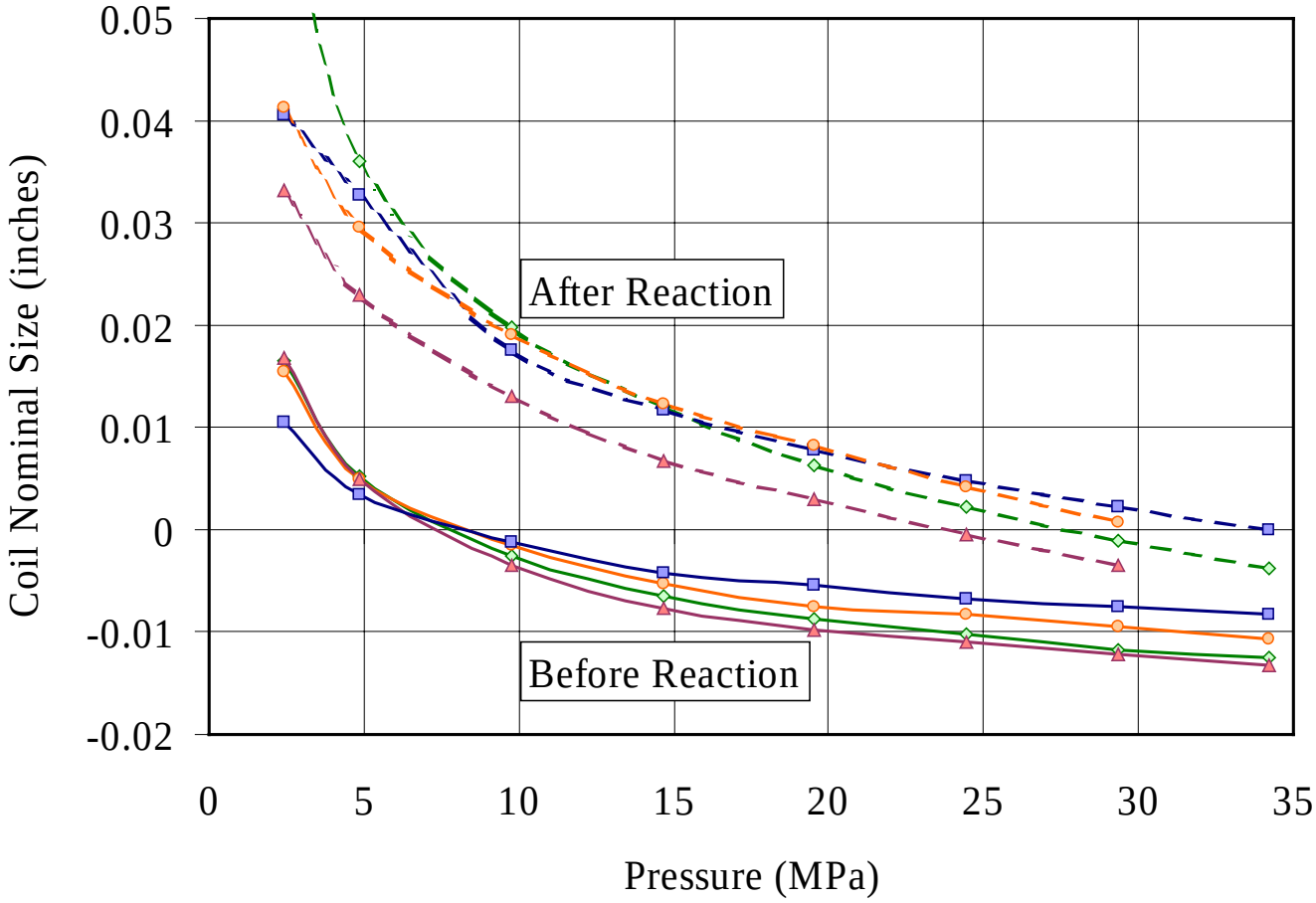


Good Bonding Between the turns even after Reaction

We were able to handle the coil easily and even perform size measurements under pressure

Azimuthal Coil Size Measurements

Before and After Reaction: Practice Half Coil #2



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Short Term Schedule

Practice Coil Impregnation:	June 10, 2000
Coil Assembly and Reaction :	June 15, 2000
Dipole Model - 1 Impregnation:	July 10, 2000
Technological Model Assembly:	July 10, 2000
Dipole Model - 1 Assembly:	August 15, 2000
Dipole Model - 1 Testing:	End of August, 2000

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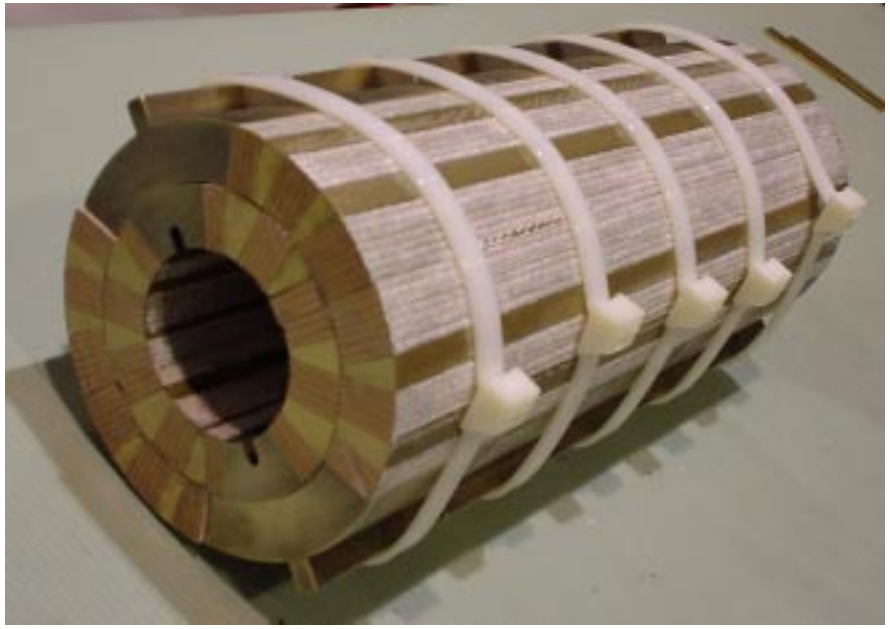
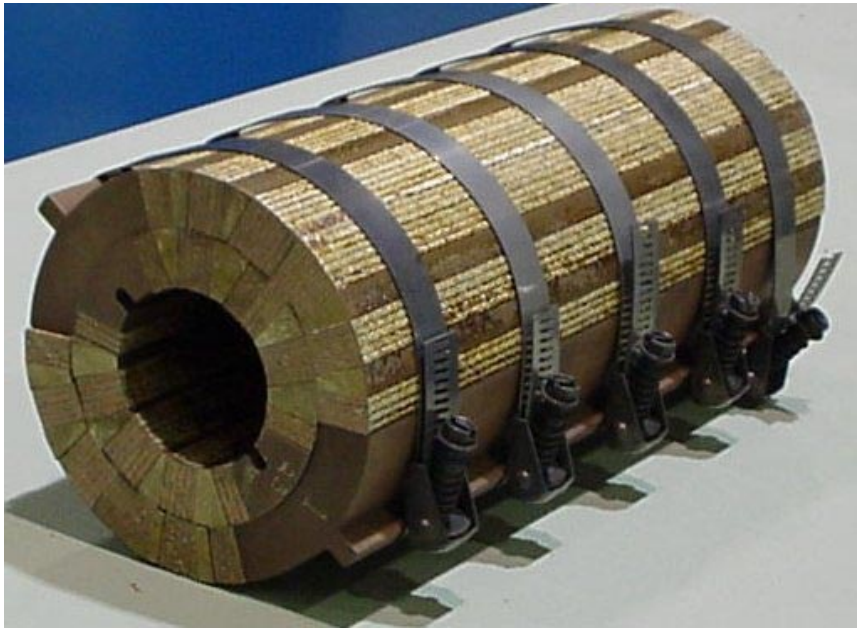
Technological Model

Model Before Reaction



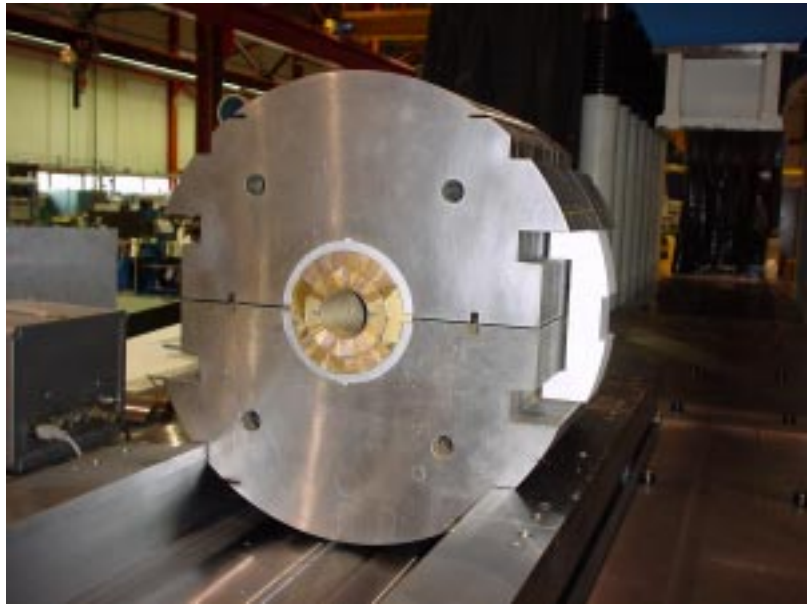
Model After Reaction



Technological Model

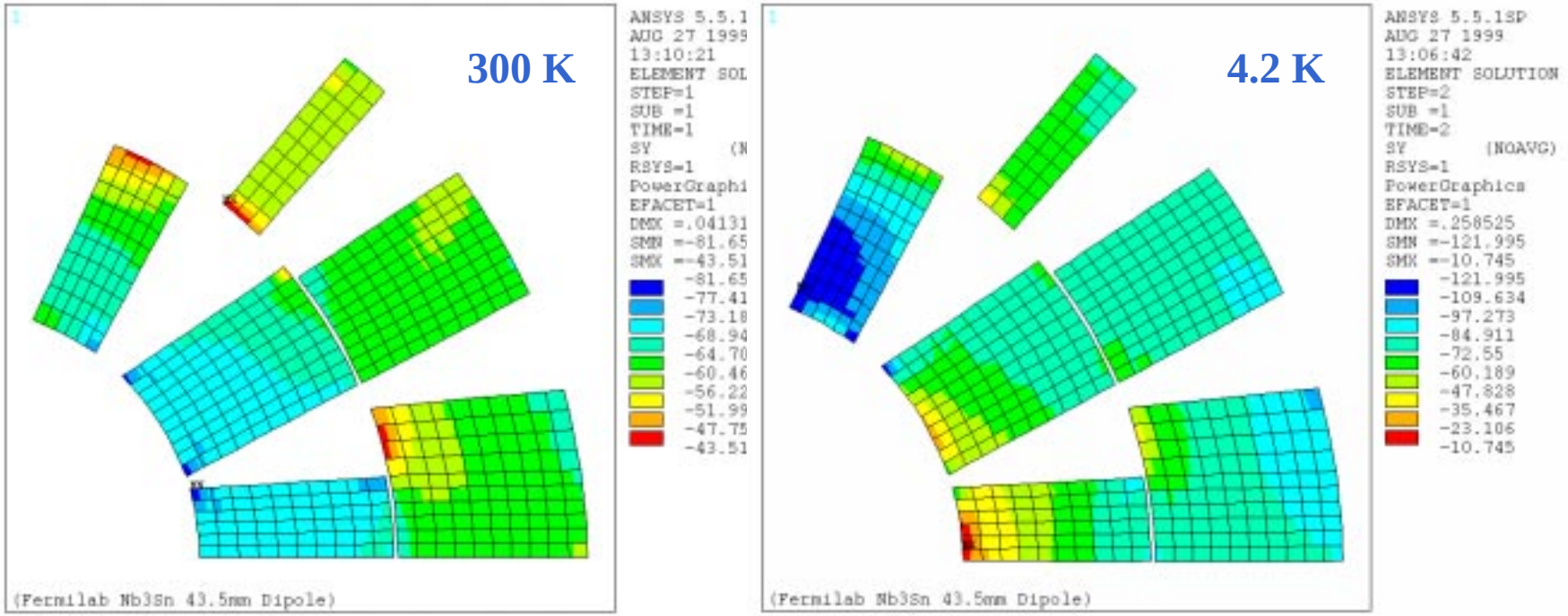
Model After Impregnation

Model with Yoke Assembly



Mechanical Analysis

Coil Azimuthal Stress Distribution



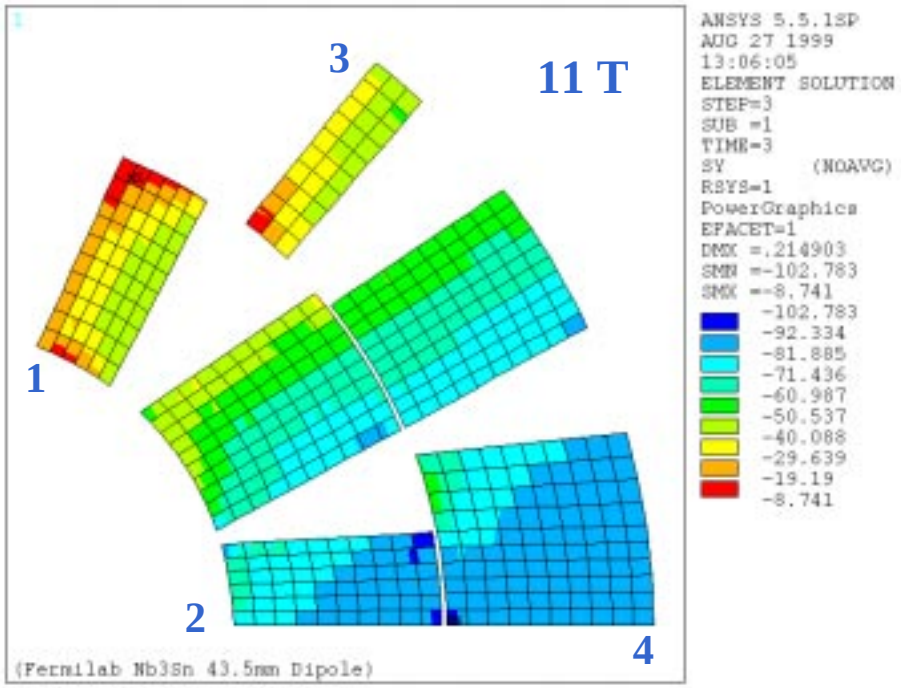
- High prestress at midplane
- Low prestress at pole

→ On Cool Down →

- Stress decreases at midplane
- Stress increases at pole

Mechanical Analysis

Coil Azimuthal Stress Distribution



Peak Coil Azimuthal Stress, MPa

Coil position	300 K		4.2 K		11 T		12 T	
	σ_θ	σ_r	σ_θ	σ_r	σ_θ	σ_r	σ_θ	σ_r
1	69	2	122	0	9	0	-5	0
2	73	2	23	0	82	0	93	0
3	60	35	85	70	51	60	44	50
4	65	40	97	52	93	94	103	100

Peak Equivalent Stress, MPa

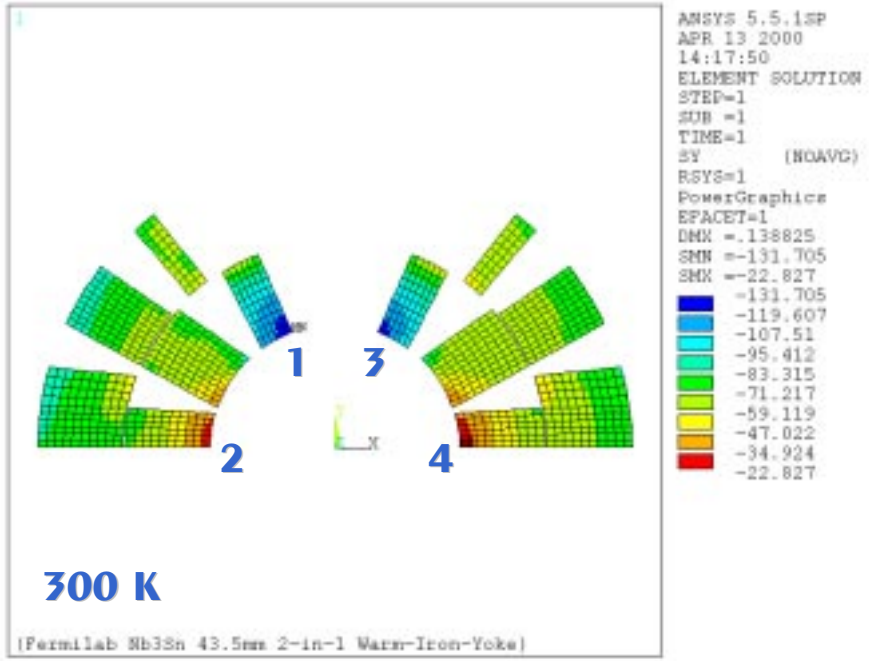
	300 K	4.2 K	11 T	12 T
Coil	80	121	100	104
Spacer	166	125	97	97
Yoke	110	110	133	133
Clamp	135	124	128	128
Skin	200	330	350	350

Mechanical Analysis: 2 - in - 1 Design

Coil Azimuthal Stress

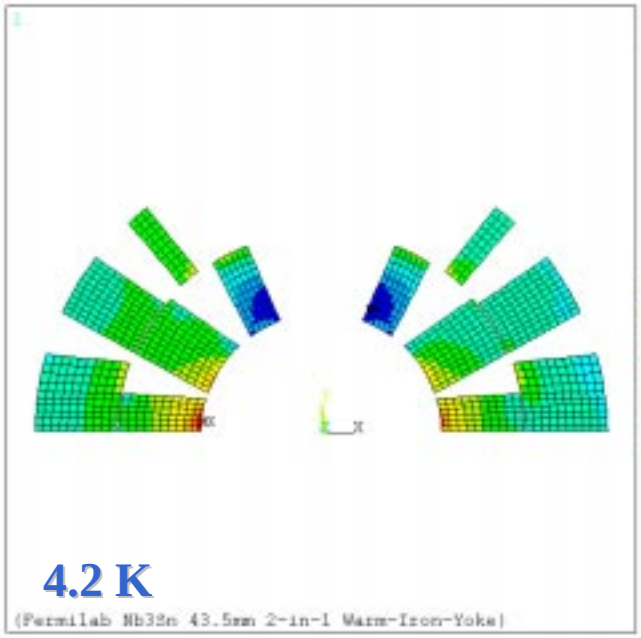
	Coil Azimuthal Stress		
Coil	300 K	4.2 K	12 T
Posiiton	MPa	MPa	MPa
Warm Iron Yoke Design			
1	131	118	2.5
2	23	-10	95
3	131	118	2.5
4	23	-10	121
Cold Iron Yoke Design			
1	120	132	0
2	60	0	68
3	121	132	-3
4	84	29	125

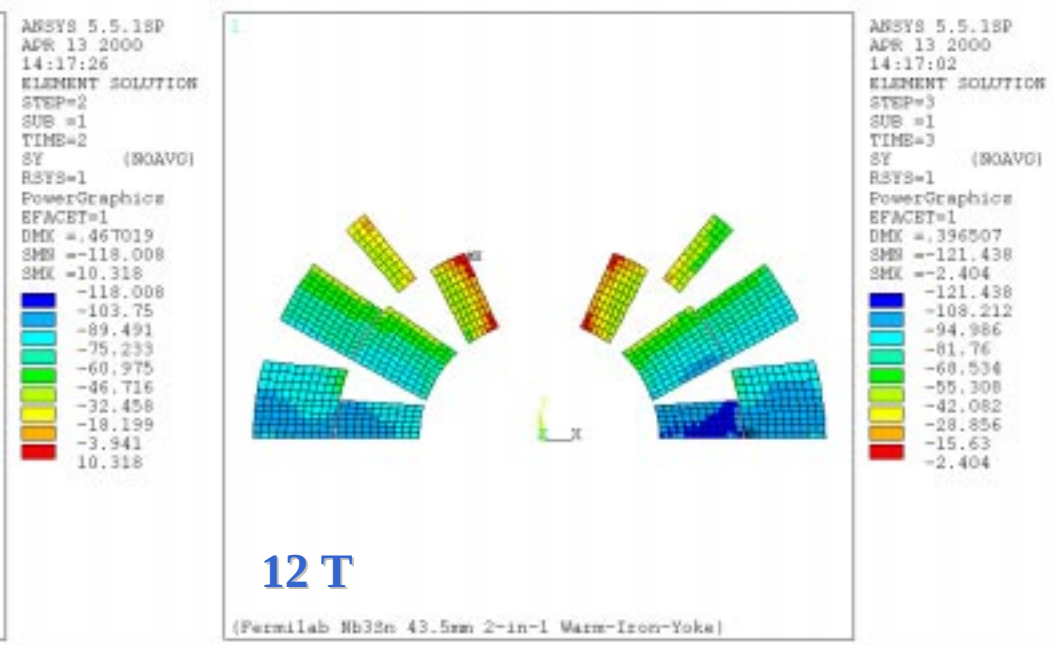
Warm Yoke Design: Stress Distribution



Mechanical Analysis: 2 - in - 1 Design

Warm Yoke Design: Stress Distribution





Summary

- Various magnet designs with the same coil block structure have been studied
- Mechanical Analysis has shown that the proposed 2 - in - 1 designs are feasible. Design Optimization is in Progress
- The proposed Coil Fabrication Technique has been successful implemented with good coil rigidity even after reaction.
- The Coil Impregnation and Magnet Assembly techniques are currently being tested on a practice coil and on a mechanical model respectively.
- The goal is to start testing the first dipole model by the end of August, 2000.

Acknowledgments

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